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(11) Publication number:

0 548 915 A1

(12)

EUROPEAN PATENT APPLICATION

(21) Application number: 92121798.0

(51) Int. Cl.⁵: F02D 41/20, H01F 7/18

(22) Date of filing: 22.12.92

(30) Priority: 23.12.91 IT TO911023

(43) Date of publication of application:
30.06.93 Bulletin 93/26(84) Designated Contracting States:
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I-10121 Torino (IT)(54) **Control circuit for predominantly inductive loads, in particular, electroinjectors.**

(57) A control circuit (100) for supplying a load with current (Ii) having a high-amplitude portion with a rapid leading edge, and a lower-amplitude portion. The circuit is input-connected (102, 103) to a low-voltage supply source, and comprises a number of actuator circuits (106) parallel-connected between the input terminals (102, 103) and each including a capacitor (Ci) and a load (Li). Each actuator circuit (106) also comprises a first controlled switch (SWi)

between the respective load (Li) and a reference line (105), for enabling energy supply and storage by the respective load. A second controlled switch (SWR) is provided between the capacitor line (112) and the load line (104), for rapidly discharging the capacitors into the load (Li) selected by the first switch (SWi) and recirculating the load current, or for charging the capacitors (Ci) with the recirculated load current.

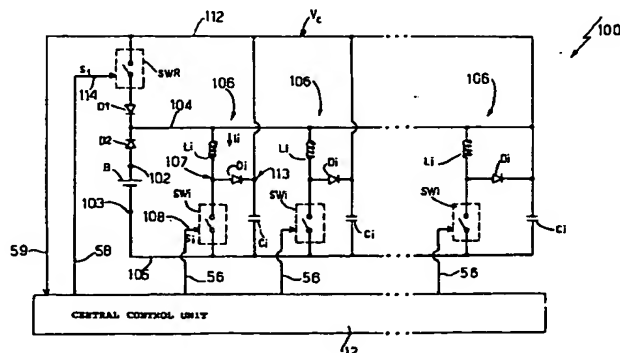


Fig.2

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The present invention relates to a control circuit for predominantly inductive loads, in particular, electroinjectors forming part of an internal combustion engine supply system.

For controlling internal combustion engine injectors, the supply current to the injectors must present a pattern comprising, in general, a rapidly increasing portion, a portion increasing more slowly, a portion oscillating about a mean value, and a rapidly decreasing portion. The circuits currently employed for achieving such a pattern substantially comprise a low-voltage supply source and a reactive circuit consisting of an inductor and capacitor for storing the energy required for producing a rapid current pulse in the load. For this purpose, the inductor is charged to a given current and then connected to the capacitor, so as to form a resonant circuit and transfer energy from the inductor to the capacitor, which is thus charged for subsequently supplying the load (injector actuator) with the required current pulse.

A major drawback of the above known circuit is that, for achieving the high currents required, large-size components such as cup-shaped or toroidal cores are used as inductors on the reactive circuit, thus increasing the size and cost of the overall circuit.

The above problem is further compounded by the fact that, for protecting the control elements of the actuators, each actuator presents a so-called "snubber" circuit comprising a capacitor and resistor connected parallel to the actuator, and which provide for absorbing and dissipating the energy of the recirculating current of the actuator. Such capacitors further increase the overall size of the circuit.

It is an object of the present invention to provide a more compact control circuit as compared with known types.

According to the present invention, there is provided a control circuit for predominantly inductive loads, in particular electroinjectors, for supplying the load with current having a high-amplitude portion with a rapid leading edge, and a lower-amplitude portion; said circuit comprising a first and second input terminal connectable to a low-voltage supply source; an energy storage circuit connected between said input terminals and including at least a capacitive element and an inductive element; a first controlled switch element located between said inductive element and a reference line, for enabling selective charging of said inductive element; a second controlled switch element for enabling rapid discharge of said capacitive element into said load; and a control unit for generating control signals for said first and second switch elements; characterized by the fact that said inductive element consists of said load.

A preferred, non-limiting embodiment of the present invention will be described by way of example with reference to the accompanying drawings, in which:

- 5 Fig.1 shows a block diagram of a supply system including the control circuit according to the present invention;
- Fig.2 shows a simplified diagram of the circuit according to the present invention;
- 10 Fig.3 shows a time graph of a number of quantities in the Fig.2 circuit and relative to a first operating mode of the circuit;
- Fig.4 shows a time graph of the Fig.3 quantities relative to a second operating mode of the circuit;
- 15 Fig.5 shows a time graph of the Fig.2-3 quantities relative to a third operating mode of the circuit.

Number 30 in Fig.1 indicates a supply system for an internal combustion engine 32, more specifically, a supercharged diesel engine. In Fig.1, the continuous lines indicate the fuel conduits, and the dotted lines the electric lines relative to measured quantity signals, controls and supply. More specifically, system 30 comprises:

- 25 - an electric supply pump 1 for ensuring a given head (1-3 bar) in fuel supply conduit 31;
- a fuel filter 2 on conduit 31, downstream from pump 1;
- 30 - a high-pressure pump 3 downstream from filter 2, for generating a high injection pressure as required (up to 1500 bar);
- a high-pressure supply line 5 from pump 3;
- 35 - a pressure regulator 4 on high-pressure supply line 5 and consisting of an electronically controlled two-way valve;
- a high-pressure fuel manifold or "rail" 6 connected to supply line 5 and having one or more connecting pipes to the injectors;
- 40 - a number of injectors 7, one for each cylinder of engine 32 and connected to manifold 6;
- a low-pressure fuel return line 8 having a number of branches: branch 8a connected to pressure regulator 4, branch 8b connected to manifold 6, and branch 8c connected to injectors 7;
- 45 - a radiator 9 on return line 8, for cooling the feed-back fuel;
- a fuel tank 10 from which fuel is withdrawn by supply conduit 31 and into which fuel is drained by return line 8;
- 50 - a system supply battery 11;
- a control and power unit (central control unit) 12 supplied by battery 11 via lines 33, and by which the unit is controlled on the basis of signals from various sensors;
- 55

- spark plugs or starters 13, one for each cylinder of engine 32, for heating the cylinder when the engine is started, and which are controlled by unit 12 via output line 34;
- an overpressure valve 21 inside manifold 6 and connected to branch 8b of return line 8;
- a combustion product exhaust conduit 45 connected to the exhaust manifold (not shown) of engine 32;
- a turbine 22 of variable geometry on exhaust conduit 45 and controlled by unit 12 via output line 46;
- an exhaust gas recirculating valve 23 on exhaust conduit 45, downstream from turbine 22, and connected to an output of unit 12 over line 47;
- a compressor 48 connected to output shaft 49 of turbine 22, supplied with ambient air by air supply conduit 50, and supplying intake manifold 36 via pressurized air supply conduit 51;
- a first pressure sensor 14 on manifold 6, connected to an input of unit 12 over line 35;
- a second pressure sensor 15 on intake manifold 36 of engine 32, for detecting the air pressure in the intake manifold and accordingly supplying an electric signal to unit 12 over line 37;
- a first temperature sensor 16 on the cylinder head of engine 32, for detecting its temperature and connected to an input of unit 12 over line 38;
- an engine speed and stroke sensor 17 on output shaft 40 of the engine and connected to an input of unit 12 over line 41;
- a third pressure sensor 18 and second outside (ambient) air temperature sensor 19 on air supply conduit 50, and connected to respective inputs of unit 12 over respective lines 53 and 54;
- an accelerator pedal position sensor 20 connected to an input of unit 12 over line 55.

Central control unit 12 is connected to control circuit 100 of injectors 7 over a number of supply lines 56, one for each injector 7, for controlling the injection phases; and controls pressure regulator 4 over line 57, both lines 56 and 57 extending from unit 12. Unit 12 and control circuit 100 are also connected over line 58 from unit 12, and line 59 from circuit 100, as explained in more detail later on.

With reference to Fig.2, circuit 100 comprises two input terminals 102 and 103 connectable to a supply source B consisting of a low-voltage battery. More specifically, terminal 102 is connected to the anode of a diode D2, the cathode of which is connected to a first common line 104 (actuator line); and terminal 103 is connected directly to a

second common line 105 (ground).

Circuit 100 also comprises a number of actuator circuits 106 parallel connected between lines 104 and 105, and each comprising an actuator Li, a storage capacitor Ci, a coupling diode Di, and a controlled electronic switch SWi. More specifically, each actuator Li, consisting of a coil wound about a core and defining the predominantly inductive load, presents one terminal connected to line 104, and the other terminal, defining node 107, connected to the anode of diode Di for connecting actuator Li to a third common line 112 (capacitance line). The cathode of each diode Di is connected to a second node 113 in turn connected to capacitance line 112 and to a first terminal of respective capacitor Ci, which provides for storing energy at a higher voltage than battery B, and the other terminal of which is connected to ground line 105. Each switch SWi, which provides for connecting actuator Li to battery B and for transferring energy from actuator Li to the circuit consisting of the parallel connection of storage capacitors Ci, is located between node 107 and ground 105, and presents a control input 108 connected to unit 12 via control line 56, over which unit 12 supplies a signal si for selecting the actuator to be enabled, as described in more detail later on.

Circuit 100 also comprises the series connection of an electronic switch SWR and a diode D1, which provide for connecting capacitance line 112 to actuator line 104 and for recirculating the current in load Li. More specifically, switch SWR presents a first terminal connected to capacitance line 112; a second terminal connected to the anode of diode D1, the cathode of which is connected to actuator line 104; and a control terminal 114 connected to unit 12 via control line 58 over which unit 12 supplies a signal s1 for controlling switch SWR. Finally, line 112 is connected to unit 12 via line 59 for enabling unit 12 to monitor the voltage on line 112.

Circuit 100 charges storage capacitors Ci to an appropriate voltage, and supplies actuators Li with current li, the pattern of which presents a high-amplitude portion with a rapid leading edge, followed by a lower-amplitude portion terminating with a rapid trailing edge, as described below with reference to Fig.s 3 to 5.

With reference to Fig.3, let us assume, to begin with, that switches SWR and SWi are open (low logic level of signals s1 and si); and storage capacitors Ci are charged to a given high voltage (voltage Vc of value Vi), so that the voltage drop between capacitance line 112 and actuator line 104 is such as to reverse-bias diodes Di, and current li in the actuators is zero.

At instant t0, switch SWR is closed, so as to switch actuator line 104 to the voltage level of

capacitance line 112.

At instant t_1 , unit 12 selects the required actuator Li by switching respective signal s_i to high and so closing respective switch SW_i , so that the selected actuator Li is connected between capacitance line 112 and ground 105, parallel to capacitors C_i with which it forms a resonant circuit. In the selected actuator, a current pulse is therefore formed consisting of a high-frequency sinusoid portion (the value of which is determined by the inductance of actuator Li and the capacitance of capacitors C_i) and produced by rapid discharge of the energy stored in capacitors C_i , thus resulting in a simultaneous rapid reduction in voltage V_c of capacitors C_i . The capacitors continue discharging up to instant t_2 , at which point voltage V_c in line 112 is approximately equal to the voltage of battery B, so that diode D2 is biased directly and connects battery B to actuator line 104. As of instant t_2 , the selected actuator Li is supplied by low-voltage battery B, and its current I_i increases slowly with a time constant of L/R , where L is the inductance of actuator Li , and R the resistance of the actuator coil, battery B, components D2 and SW_i , and the connecting line. In this phase, the selected actuator diode Di remains reverse-biased.

The above phase continues up to instant t_3 , at which point switch SW_i is opened (signal s_i switched to low), so that the selected actuator diode Di is biased directly and operates as a "free-wheeling" diode, thus enabling discharge of the previously charged actuator Li and recirculation of current I_i via capacitance line 112 and switch SWR . In this phase, current I_i therefore decreases with a time constant of L/R , where R is the resistance of the actuator coil and components Di , SWR and D1.

At instant t_4 , switch SW_i is again closed, the selected actuator Li is again charged by battery B, and respective diode Di opens to disconnect capacitance line 112. In this phase, current I_i in the actuator again increases with a time constant of L/R , where R is the resistance of the actuator coil, components B, D2 and SW_i , and the connecting line, despite the L value differing as compared with phase t_2 - t_3 , due to the different current level. When switch SW_i is opened at instant t_5 , actuator Li is again discharged, so that, by appropriately opening and closing switch SW_i , the current in actuator Li may be maintained in such a manner as to oscillate about a predetermined medium-low value.

For rapidly discharging actuator Li , switches SWR and SW_i are opened successively. In the Fig.3 case, in particular, switch SWR is opened at instant t_6 with switch SW_i open. In this phase, diode Di is biased directly, so as to connect actuator Li to capacitance line 112 and again form a resonant circuit; actuator Li therefore discharges rapidly into capacitors C_i ; current I_i decreases in

the form of a high-frequency sinusoid portion; and the energy previously stored by actuator Li is transferred to capacitors C_i , the voltage of which thus increases rapidly. The above phase continues until the current in actuator Li is zeroed, which corresponds to a first charge of capacitors C_i to voltage V_2 , at which point diode Di is disabled for preventing the sign of the current in the inductor from being inverted (instant t_7). Subsequently, capacitors C_i remain charged to voltage V_2 , by virtue of being isolated from the rest of the circuit.

As shown in Fig.3, at instant t_8 , unit 12 again closes one or more of switches SW_i , so as to again close the circuit including battery B and the actuator Li relative to each closed switch SW_i , so that each actuator Li is supplied with current increasing with a time constant of L/R . In this phase, capacitors C_i remain isolated. At instant t_9 , switch SW_i (or all the switches closed previously) is again opened, so that, as in interval t_6 - t_7 , energy is transferred from the actuator to capacitors C_i , current I_i in actuator Li is zeroed (instant t_{10}), and the voltage in capacitance line 112 increases. By repeating the above two phases and appropriately selecting the closing times of switch/es SW_i , it is possible to charge the capacitors gradually to the required level V_1 , by first charging actuators Li to such a value as to avoid activating them, and then discharging the actuators into the capacitors.

The Fig.2 circuit also provides for a second operating mode, as shown in Fig.4. In this case, as in the Fig.3 mode, capacitors C_i are initially charged to level V_1 ; switches SWR and SW_i are open; actuator line 104 is switched to level V_1 when switch SWR is closed (instant t_0); closure of a given switch SW_i (instant t_1) provides for selecting a given actuator Li , generating a current pulse in the actuator, and rapidly charging the actuator at the expense of capacitors C_i , which discharge to approximately the value of battery B (instant t_2); and the selected actuator Li is subsequently supplied by battery B, until the relative switch SW_i is opened (instant t_3). The fact that, in the second operating mode, switch SWR is opened in the interval t_2 - t_3 in no way affects operation of the circuit as described above.

Unlike the Fig.3 mode, however, when switch SW_i is opened (instant t_3), actuator Li is prevented from discharging through the circuit including switch SWR , so that energy can only be transferred from actuator Li to capacitors C_i , thus resulting in a first charge of capacitors C_i in interval t_3 - t_4 , as shown in Fig.4. When switch SW_i is closed (instant t_4), actuator Li is again connected to the circuit including battery B, and so begins charging via diode D2, while the relative diode Di is disabled for disconnecting actuator Li from capacitance line 112, which is thus maintained at the previous volt-

age level. At instant t_5 , switch SW_i is again opened, so that the energy stored by actuator Li in the foregoing interval t_4 - t_5 is transferred to capacitors C_i , which are thus charged directly by the selected actuator during the low-current operating phase, using the recirculating current of the actuator itself.

The current in the actuator is zeroed by keeping the relative switch SW_i open subsequent to instant t_7 , as shown in Fig.4.

In the Fig.4 operating mode, the voltage of capacitors C_i may be limited to a predetermined value by appropriately delaying the opening of switch SWR subsequent to instant t_3 , so that the initial opening phases of switches SW_i provide for recirculating the actuator current through switch SWR , without charging capacitors C_i , which are only charged after a given number of opening and closing cycles of switches SW_i .

In other words, according to the present invention, the energy stored in actuators Li , instead of being dissipated, as in known circuits, during the recirculating phase, is employed for charging capacitors C_i , which in turn provide for rapidly supplying the selected actuators. As such, energy is transferred continually in alternate phases between the actuators and capacitors, thus reducing the number of components and dissipation of the circuit, as well as increasing the rapidity with which the various phases are performed. Moreover, connection of actuator circuits 106 to the same line 104 provides for transferring energy from one circuit 106 to the next according to the injection phases provided for by unit 12.

The resulting high-speed response of the circuit also provides for achieving a pilot injection phase prior to actual injection. Proposals have been made, in fact, for preceding actual injection with a shorter pilot injection phase, for initiating combustion with a limited amount of fuel and so reducing the rate of heat release, noise level, and the formation of nitric oxide. Despite the proved effectiveness of a pilot injection phase, particularly at low speed and/or under partial load conditions, the delays introduced by the control circuit components and injectors and the operating frequency involved currently prevent two distinct injection phases from being achieved in rapid succession. In actual practice, in fact, the two phases merge, with one continuous opening operation of the injector ranging from the start of the pilot phase to the end of the actual injection phase.

By virtue of transferring energy from the actuators to the capacitors during the discharge phase, however, the present invention provides for achieving a pilot phase temporally distinct from the actual injection phase.

One embodiment of such a pilot injection phase will be described with reference to Fig.5 showing time graphs of quantities s_1 , s_i , V_C and li . Initially, signals s_1 and s_i are low, capacitors C_i are charged to voltage V_C of value V_1 , and the actuators are discharged. As in Fig.s 3 and 4, at instant t_0 , switch SWR is closed (by switching signal s_1) and, at instant t_1 , switch SW_i of the selected actuator is closed, thus generating a current pulse li in the actuator due to rapid discharge of capacitors C_i . At instant t_2 , the voltage in capacitance line 112 equals that of battery B , which therefore takes over supply of the actuator from capacitors C_i , thus enabling a further, slower, increase in current li of actuator Li (pilot injection phase). At instant t_3 , switch SWR is again opened; and, at instant t_4 , switch SW_i is also opened, so that the current in actuator Li falls rapidly to zero at instant t_5 , and, at the same time, the voltage in capacitors C_i increases rapidly to value V_3 by virtue of the energy in actuator Li being transferred to capacitors C_i . At instant t_6 , switch SWR is again closed; and, at instant t_7 , switch SW_i of the actuator previously selected for the pilot phase is again closed, followed by the actual, longer, injection phase according to either one of the operating modes in Fig.s 3 and 4. In the Fig.5 example, the actual injection phase is performed as shown in Fig.3 and therefore requires no further description.

By virtue of employing the actuators for charging capacitors C_i , the circuit according to the present invention provides for achieving the required current patterns with no need for auxiliary inductors or capacitors. Moreover, by virtue of the recirculating current of actuators Li being absorbed by and charging capacitors C_i , no "snubbing" capacitors are required, as on known circuits, for protecting switches SW_i , thus greatly reducing the size and cost of the circuit according to the present invention.

To those skilled in the art it will be clear that changes may be made to the circuit as described and illustrated herein without, however, departing from the scope of the present invention. For example, the number of circuits 106 depends on the number of actuators Li , and may vary as required.

Claims

1. A control circuit for predominantly inductive loads, in particular electroinjectors, for supplying the load with current (li) having a high-amplitude portion with a rapid leading edge, and a lower-amplitude portion; said circuit (100) comprising a first and second input terminal (102, 103) connectable to a low-voltage supply source (B); an energy storage circuit (106) connected between said input terminals

and including at least a capacitive element (Ci) and an inductive element (Li); a first controlled switch element (SWi) located between said inductive element and a reference line (105), for enabling selective charging of said inductive element; a second controlled switch element (SWR) for enabling rapid discharge of said capacitive element into said load; and a control unit (12) for generating control signals (s_i, s_r) for said first and second switch elements (SWi, SWR); characterized by the fact that said inductive element consists of said load (Li).

2. A circuit as claimed in Claim 1, characterized by the fact that said load (Li) presents a first terminal (104) connected to said first input terminal (102); said reference line (105) is connected to said second input terminal (103); said load (Li) is connected to said first switch element (SWi) by a second terminal defining a first node (107) connected to a second node (113) consisting of a first terminal of said capacitive element (Ci); and said second switch element (SWR) is located between said second node (113) and said first terminal (104) of said load.
3. A circuit as claimed in Claim 2, characterized by the fact that said capacitive element (Ci) presents a second terminal connected to said reference line (105).
4. A circuit as claimed in Claim 2 or 3, characterized by the fact that said first and second nodes (107, 113) are connected by a first unipolar switch (Di) enabling current to flow from said load (Li) to said capacitive element (Ci); by the fact that, between said first input terminal (102) and said first terminal (104) of said load (Li), there is provided a second unipolar switch (D2) enabling current to flow from said first input terminal to said load; and by the fact that, between said second switch element (SWR) and said first terminal (104) of said load, there is provided a third unipolar switch (D1) enabling current to flow from said second switch element to said load.
5. A circuit as claimed in claim 4, characterized by the fact that said first, second and third unipolar switches (Di, D2, D1) consist of junction diodes.
6. A circuit as claimed in one of the foregoing Claims, characterized by the fact that said first and second switch elements (SWi, SWR) both present a control terminal (108, 114) connect-

ed to said control unit (12).

7. A circuit as claimed in Claim 4, characterized by the fact that it comprises means (12) for closing said first and second switch elements (SWi, SWR) when said capacitive element (Ci) is charged, and rapidly discharging said capacitive element into said load (Li); means for consecutively opening and closing said first switch element (SWi) when said second switch element (SWR) is closed, and producing small current pulses in said load with no energy transfer between said load and said capacitive element; and means for consecutively opening and closing said first switch element (SWi) when said second switch element (SWR) is open, for producing small current pulses in said load and subsequently transferring energy from said load to said capacitive element.
8. A circuit as claimed in Claim 4, wherein said load comprises an electroinjector actuator; characterized by the fact that it comprises means (12) for closing said first and second switch elements (SWi, SWR) when said capacitive element (Ci) is charged, and rapidly discharging said capacitive element into said load (Li); and means for consecutively opening said first and second switch elements (SWi, SWR), and rapidly discharging said load (Li) into said capacitive element (Ci), for achieving a pilot injection phase of said electroinjector.
9. A circuit as claimed in any one of the foregoing Claims and having a number of parallel-connected loads (Li); characterized by the fact that it comprises a number of energy storage circuits (106), each including a load (Li) as the inductive element, and a first switch element (SWi) selectively controlled by said control unit (12) for activating one of said loads.
10. A circuit as claimed in any one of the foregoing Claims, for controlling the actuators of electroinjectors forming part of the supply system (30) of an engine (32); characterized by the fact that said system comprises: an electric supply pump (1) on the fuel supply conduit (31); a fuel filter (2) on said supply conduit (31), downstream from said pump (1); a high-pressure pump (3) downstream from said filter (2); a high-pressure supply line (5) from said high-pressure pump (3); a pressure regulator (4) on said supply line (5); a fuel manifold (6) connected to said supply line (5); a number of injectors (7) connected to said fuel manifold (6); a low-pressure fuel return line (8) connected to said pressure regulator (4), to said

fuel manifold (6), and to said injectors (7); a radiator (9) on said return line (8); a fuel tank (10) into which said supply conduit (31) and said return line (8) extend; an overpressure valve (21) housed in said fuel manifold (6) and connected to said return line (8); a combustion product exhaust conduit (45); a variable-geometry turbine (22) on said exhaust conduit (45) and controlled by said control unit (12); an exhaust gas recirculating valve (23) on said exhaust conduit (45), downstream from said turbine (22) and connected to said control unit (12); a compressor (48) connected to the output shaft (49) of said turbine (22) and to the intake manifold (36); a first pressure sensor (14) on said fuel manifold (6) and connected to said control unit (12); a second pressure sensor (15) on said intake manifold (36); a first temperature sensor (16) on the cylinder head of said engine (32) and connected to said control unit (12); an engine speed and stroke sensor (17) on the output shaft (40) of said engine and connected to said control unit (12); a third pressure sensor (18) and second ambient air temperature sensor (19) on the air supply conduit (50) and connected to said control unit (12); and an accelerator pedal position sensor (20) connected to said control unit (12).

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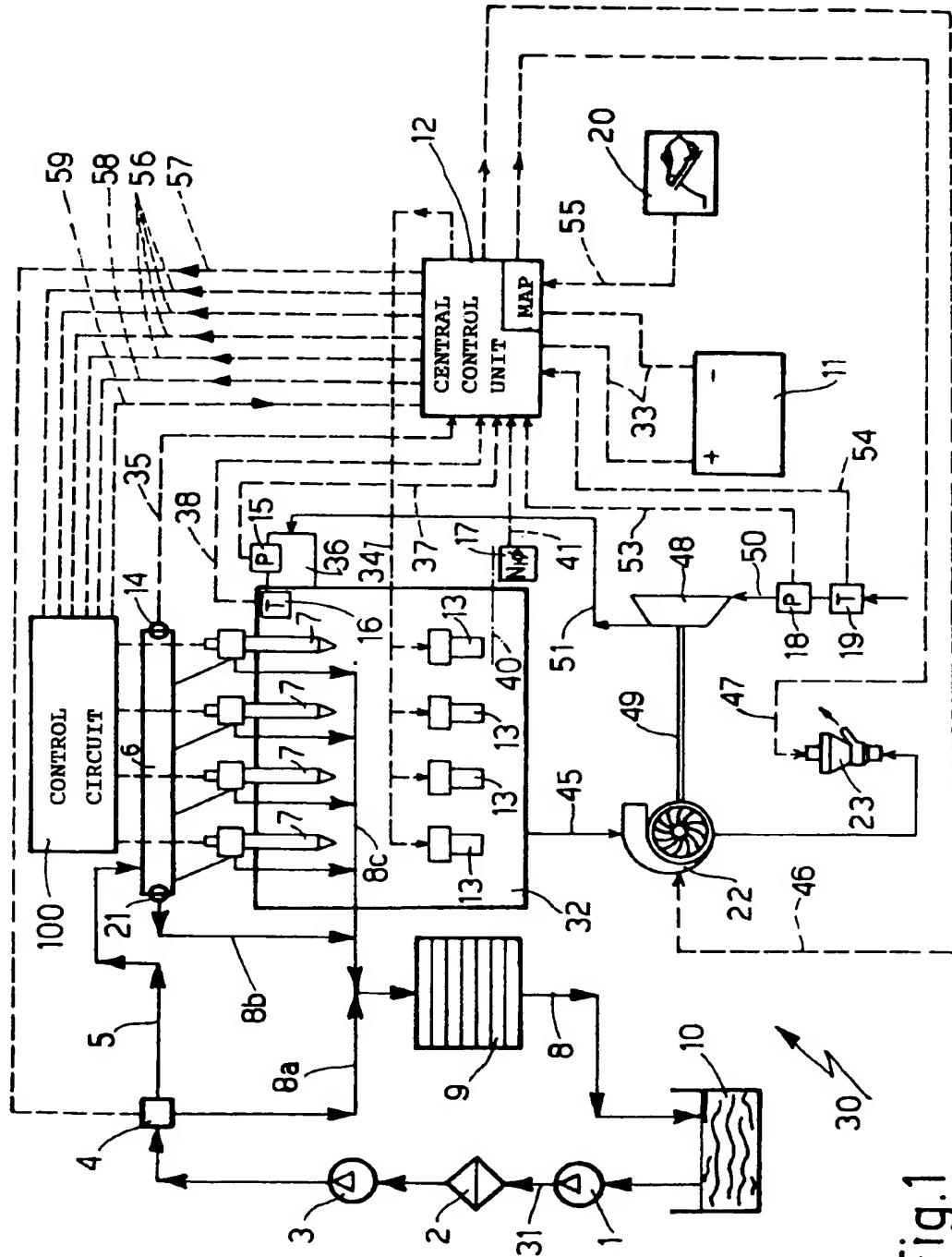


Fig.1

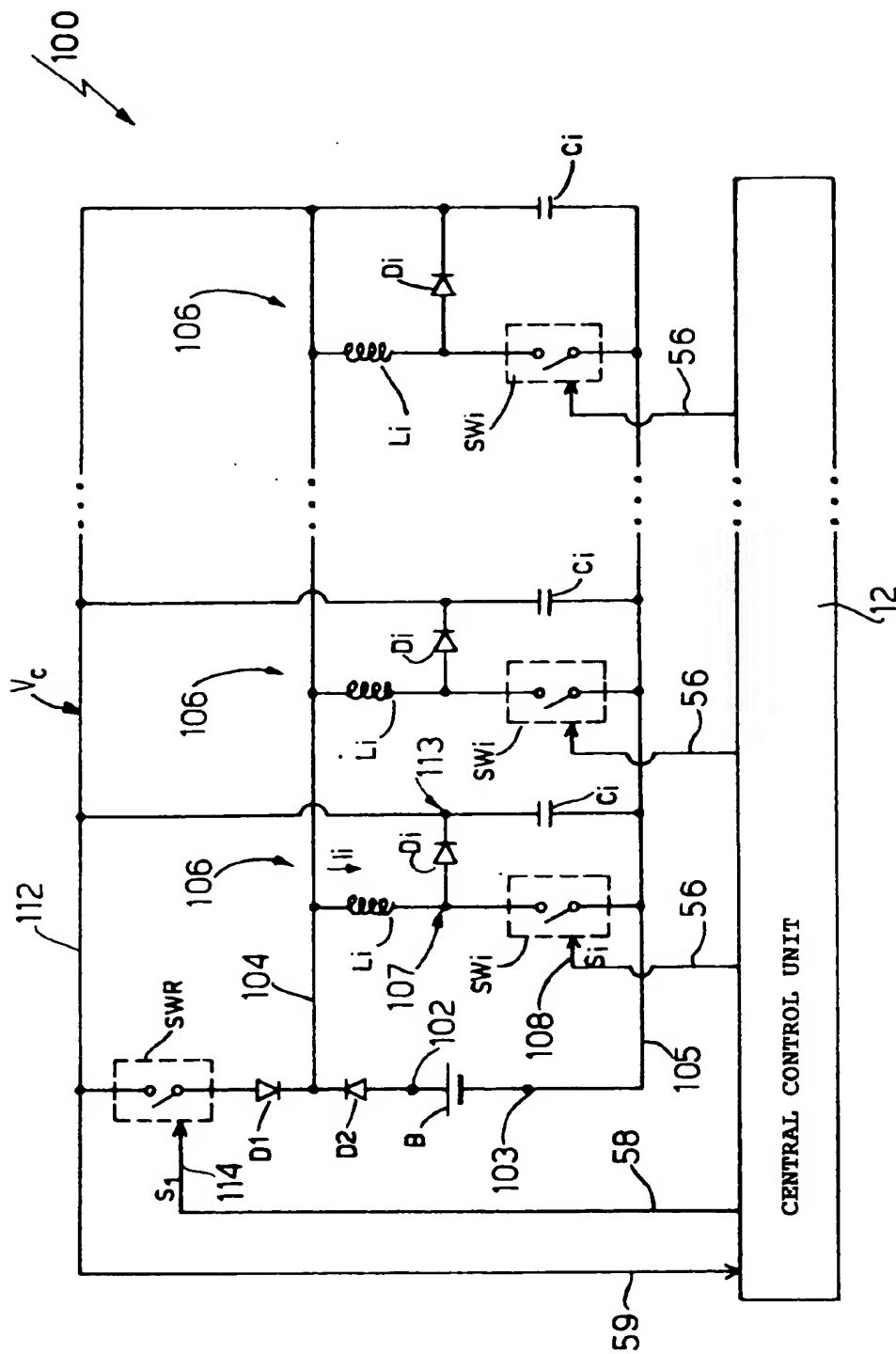


Fig. 2

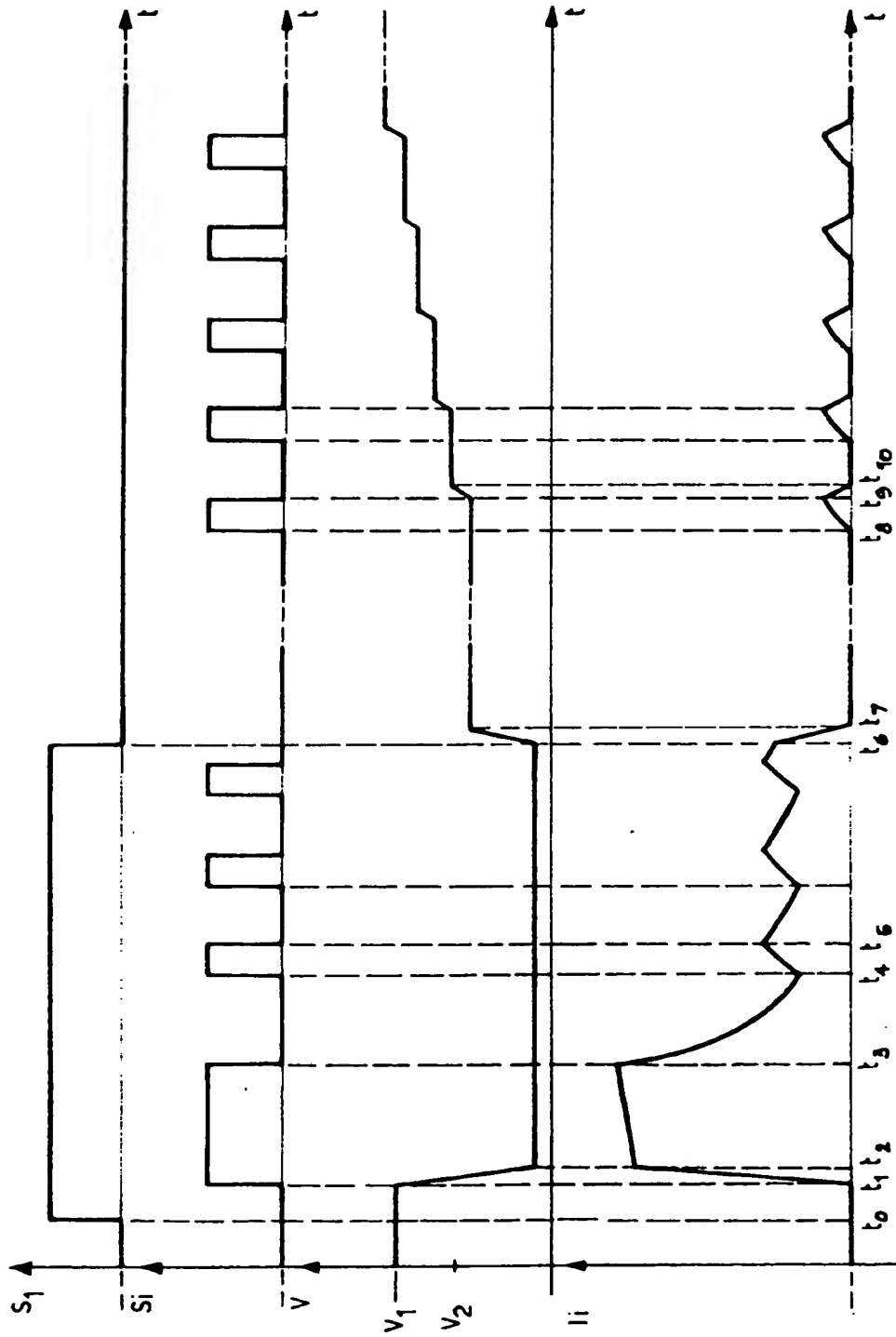


Fig.3

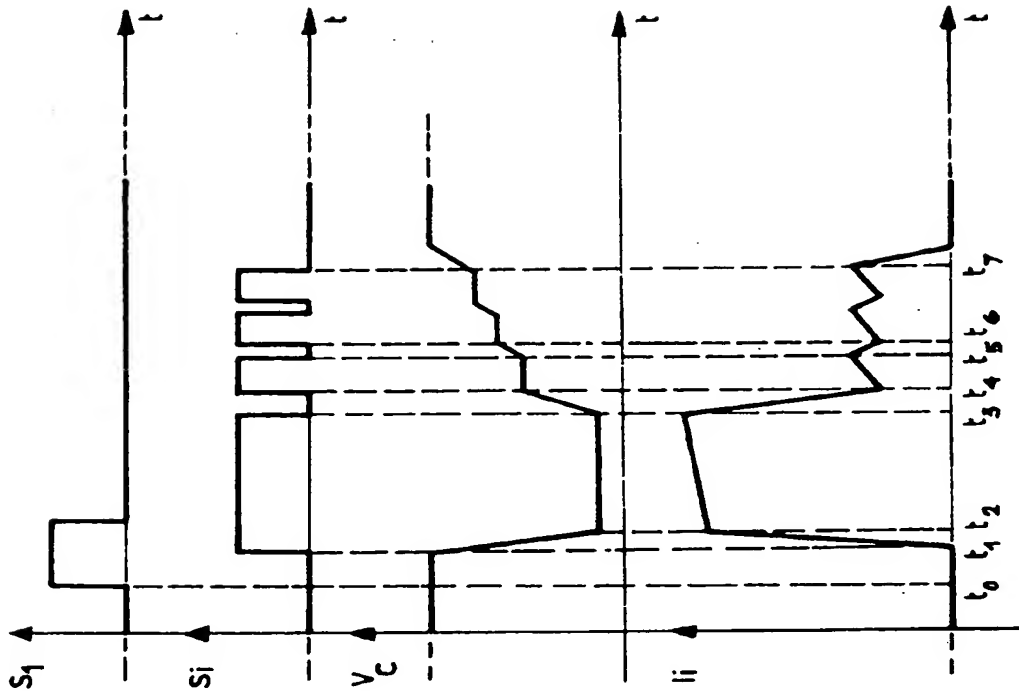


Fig.4

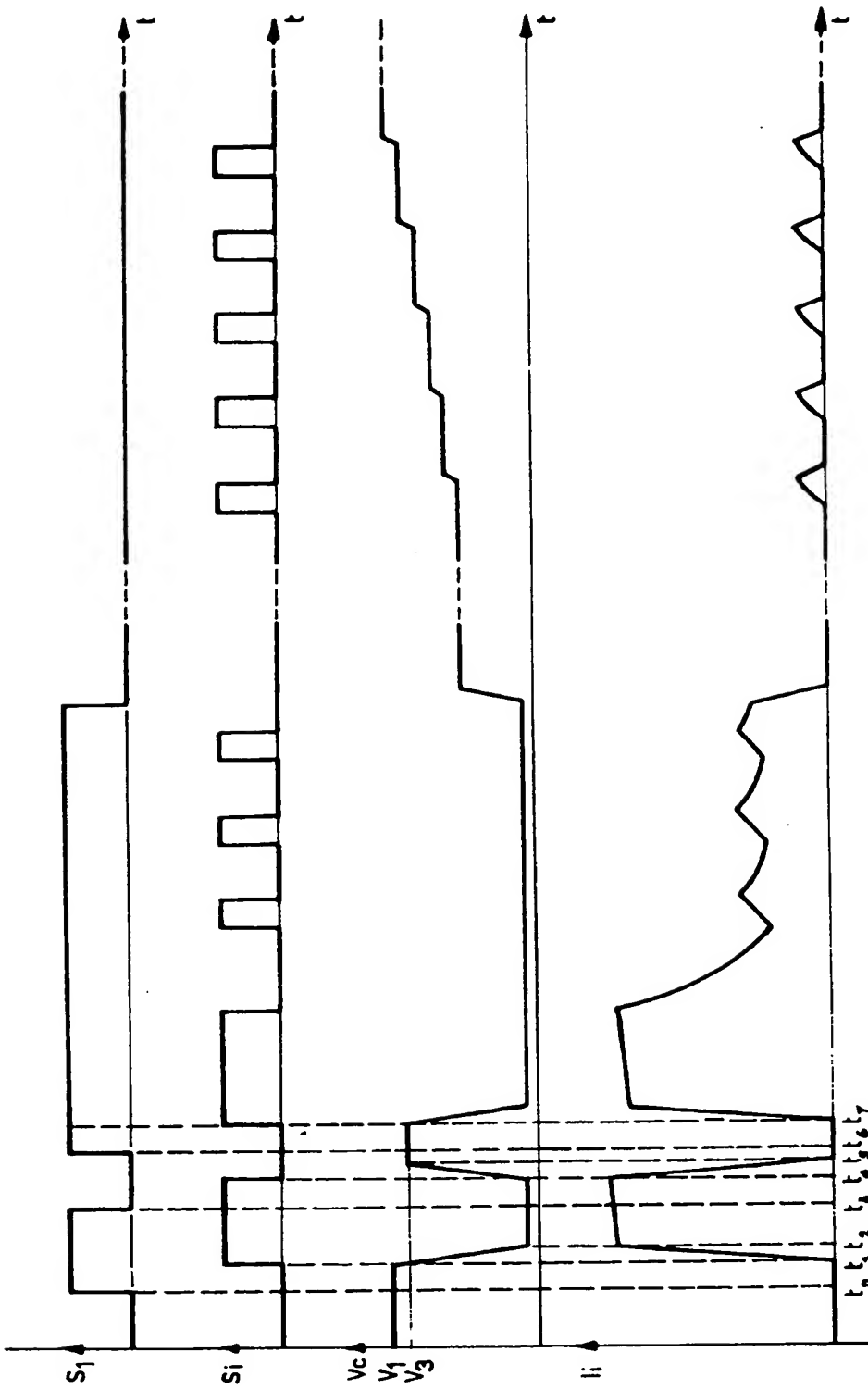


Fig.5



European Patent
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EUROPEAN SEARCH REPORT

Application Number

DOCUMENTS CONSIDERED TO BE RELEVANT			EP 92121798.0
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	<u>FR - A - 2 538 942</u> (RENAULT) * Claims; page 2, line 33 - page 4, line 11; fig. 1,2 * --	1-3,6 9	F 02 D 41/20 H 01 F 7/18
A	<u>US - A - 4 775 914</u> (INCARDONA) * Claims; column 2, lines 9-59; fig. 1,2 * --	1-4	
A	<u>FR - A - 2 653 493</u> (PEUGEOT et al.) * Abstract; fig. 1 * ----	1,10	
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
			F 02 D H 01 F 7/00 F 16 K 31/00 H 01 H 47/00 H 03 K 17/00
The present search report has been drawn up for all claims			
Place of search VIENNA		Date of completion of the search 23-02-1993	Examiner KUTZELNIGG
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DOCUMENTS CITED IN THE APPLICATION

DOCUMENT NO.	PAGE NO.	ENGLISH COUNTERPART
<input type="checkbox"/> JP-B2-2598595	1	<input checked="" type="checkbox"/> EP 0 548 915 A1
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USA APPLICATIONS OF APPLICANT

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